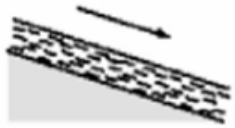
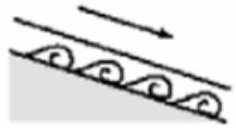
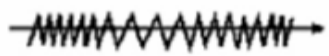
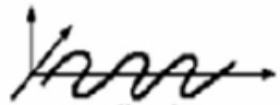
Principles of robot locomotion

Examples found in Nature

Type of motion	Resistance to motion	Basic kinematics of motion
Flow in a Channel 	Hydrodynamic forces	Eddies 
Crawl 	Friction forces	Longitudinal vibration 
Sliding 	Friction forces	Transverse vibration 
Running 	Loss of kinetic energy	Oscillatory movement of a multi-link pendulum 
Jumping 	Loss of kinetic energy	Oscillatory movement of a multi-link pendulum 
Walking 	Gravitational forces	Rolling of a polygon (see figure 2.2) 

- Successful in moving through a wide variety of harsh environments…

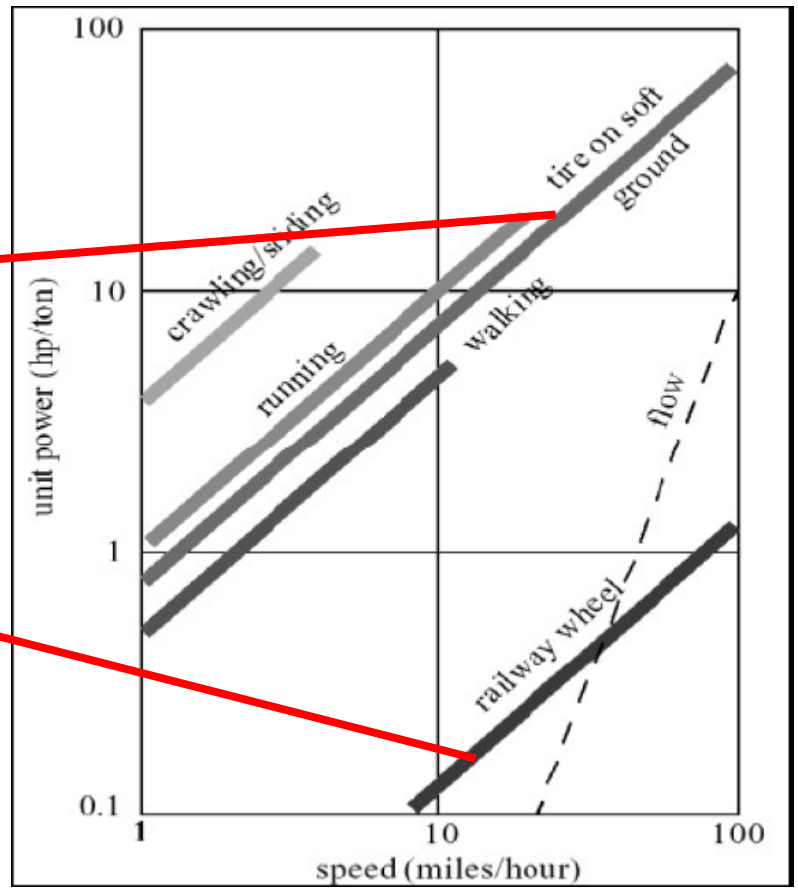
but……..

- Difficult to imitate (biomimetics)
- High power consumption (as we will see later)

Energy Consumption and Speed

Rolling friction increases

Ground dependences



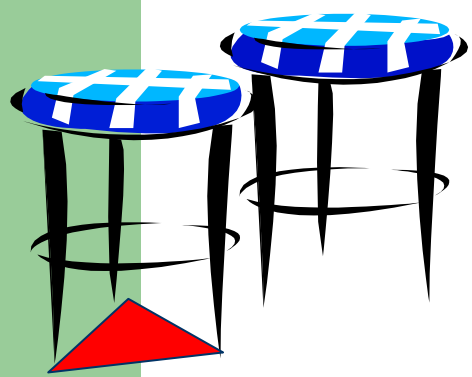
Locomotion

- Locomotion means that the robot moves by imparting force to the fixed environment

- Three core issues
  - stability
  - characteristics of contact
  - type of environment

Stability (Legged Locomotion)

- Stability: robot will not overturn
- Static stability
  - Balance is maintained with no need for motion
    - ➡ at least three legs (points of ground contact) are required (e.g. stool)



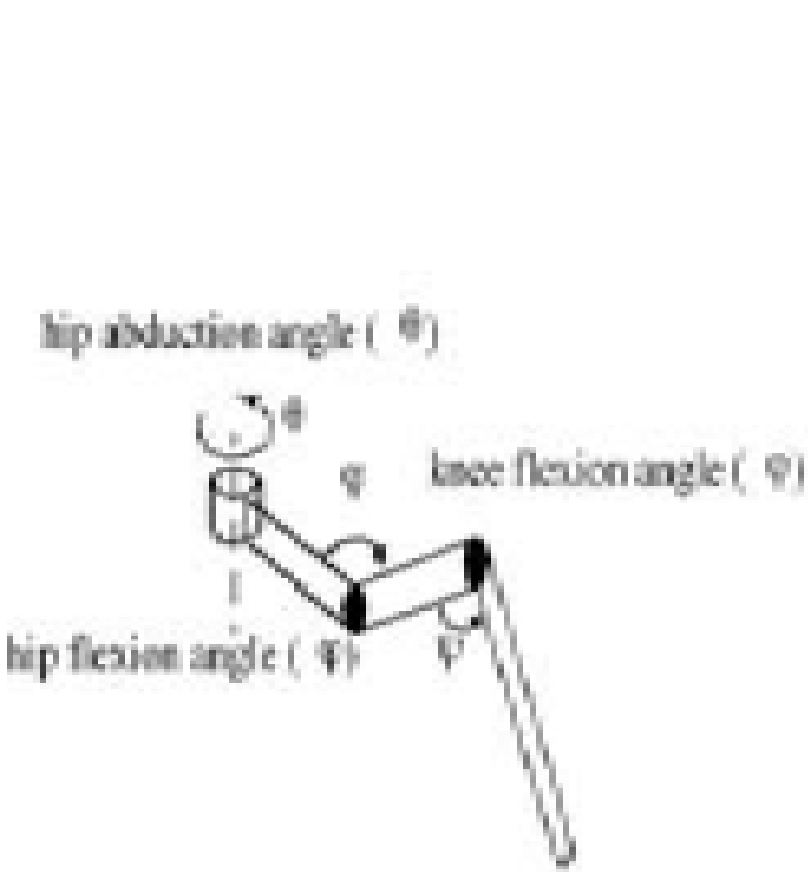
Balance is maintained when the center of mass is within the red triangle

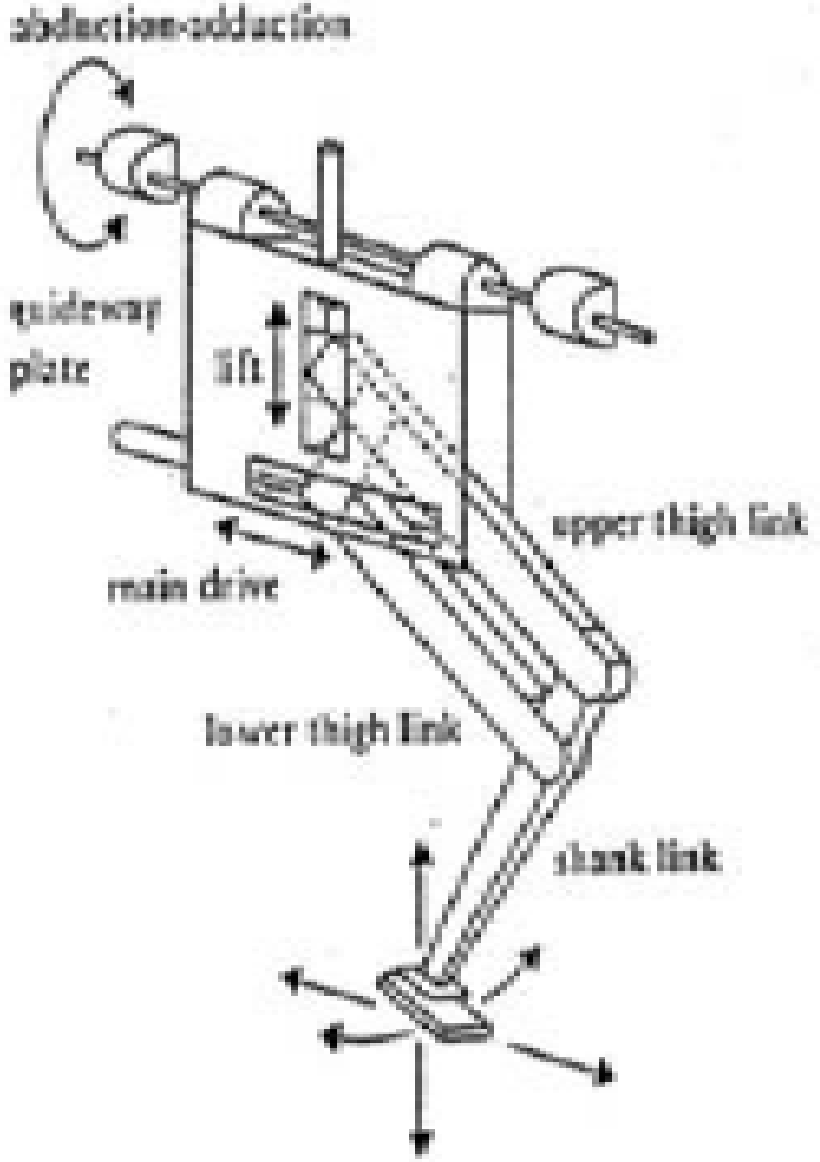
- *…more in general: stability is given, when the centre of mass is completely within the zone of stability (support polygon) and the base is greater than zero*

Minimal polygon which contains all points of ground contact

Leg Configuration

- DOF = Degree of freedom (the set of independent displacements that specify completely the displaced or deformed position of the body or system)
- A minimum of two DOF are required to move a leg forward.
- One joint for lifting and one for swinging
- For each DOF one joint is required


hip abduction angle ( )
knee flexion angle ( )
hip flexion angle ( )


abduction-adduction
guideway plate
lift
upper thigh link
main drive
lower thigh link
shank link

- Adding DOF means:
  - Increasing the maneuverability
  - Increasing the range of terrain on which the robot is able to walk

…but it also means…

  - Increasing the energy consumption
  - Making the control more difficult
  - Additional body mass

Gait

- The number of possible gaits depends on the number of legs
- A gait is a (periodic) sequence of lift and release **events** of the individual leg
- Number of possible events ***N*** for a robot with ***k*** legs :

$$N = (2k - 1)!$$

- k=2 : N = (2*2-1)! = 6
- *The different events are:*
  1. *Lift right leg*
  2. *Lift left leg*
  3. *Release right leg*
  4. *Release left leg*
  5. *Lift both legs together*
  6. *Release both legs together*

- k=6 : N = (2*6-1)! = 39916800

Wheeled Locomotion

- Most popular locomotion mechanism

  Because…….

- …wheels are energy efficient
- …wheels are easy to implement
- …wheeled vehicles have no balance problems, if there are more than two wheels

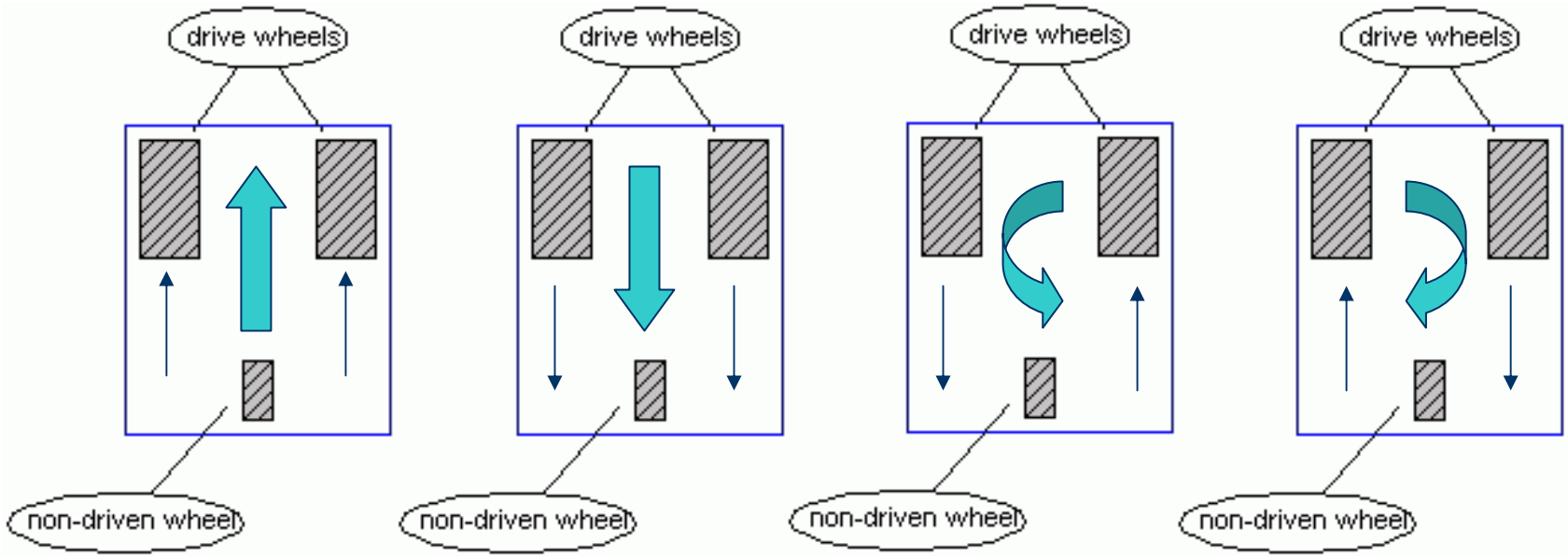
Wheeled Locomotion Systems

- Differential drive
- Car type drive
- Pivot drive

Differential Drive

- This is the most commonly used form of locomotion system used in mobile robots as it’s the simplest and easiest to implement
- It has a free moving wheel in the front accompanied with a left and right wheel.The two wheels are separately powered
- When the wheels move in the same direction the machine moves in that direction. Turning is achieved by making the wheels oppose each other’s motion, thus generating a couple

Differential Drive Cont…



- Black arrows denote the direction of wheel. The green ones show robot movement

Differential Drive Cont…

- In-place (zero turning radius) rotation is done by turning the drive wheels at the same rate in the opposite direction
- Arbitrary motion paths can be implemented by dynamically modifying the angular velocity and/or direction of the drive wheels
- Total of two motors are required, both of them are responsible for translation and rotational motion

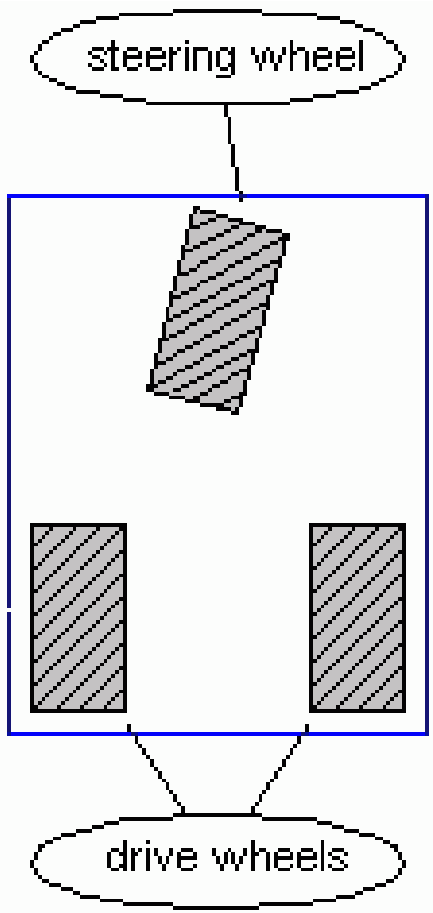
Differential Drive An Analysis

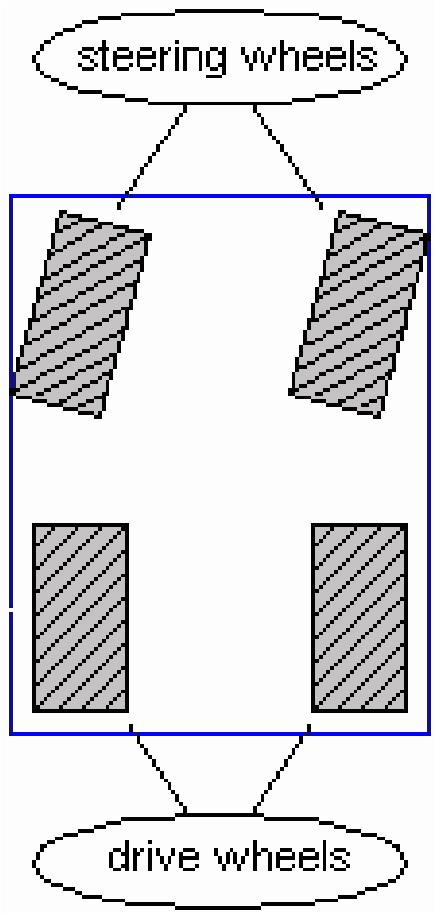
- Simplicity and ease of use makes it the most preferred system by beginners
- Independent drives makes it difficult for straight line motion. The differences in motors and frictional profile of the two wheels cause them to move with slight turning effect
- The above drawback must be countered with appropriate feedback system. Suitable for human controlled remote robots

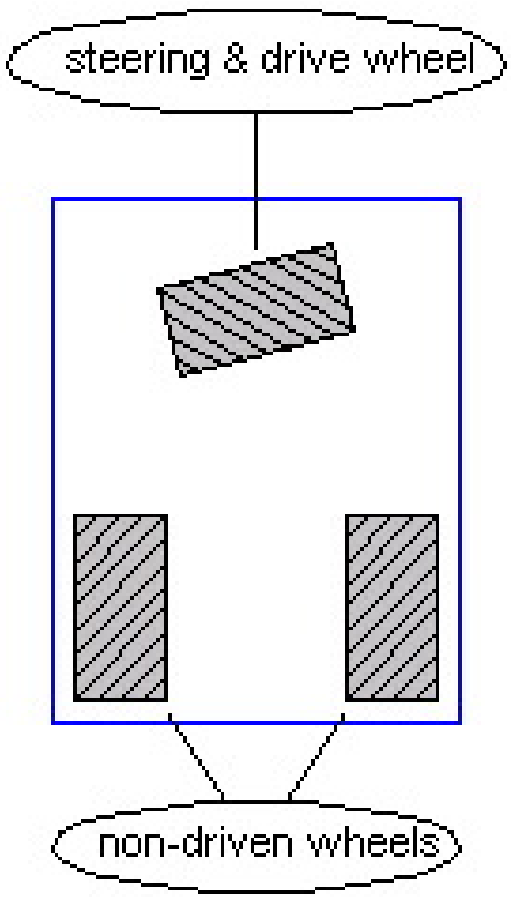
Car Type Drive

- This is the car type drive and the most common in real world but not in robot world
- It is characterized by a pair of driving wheels and a separate pair of steering wheels
- The translation and rotation are independent of each other. But translation and rotation are interlinked hence this system faces severe path planning problem

Car Type Drive Cont…





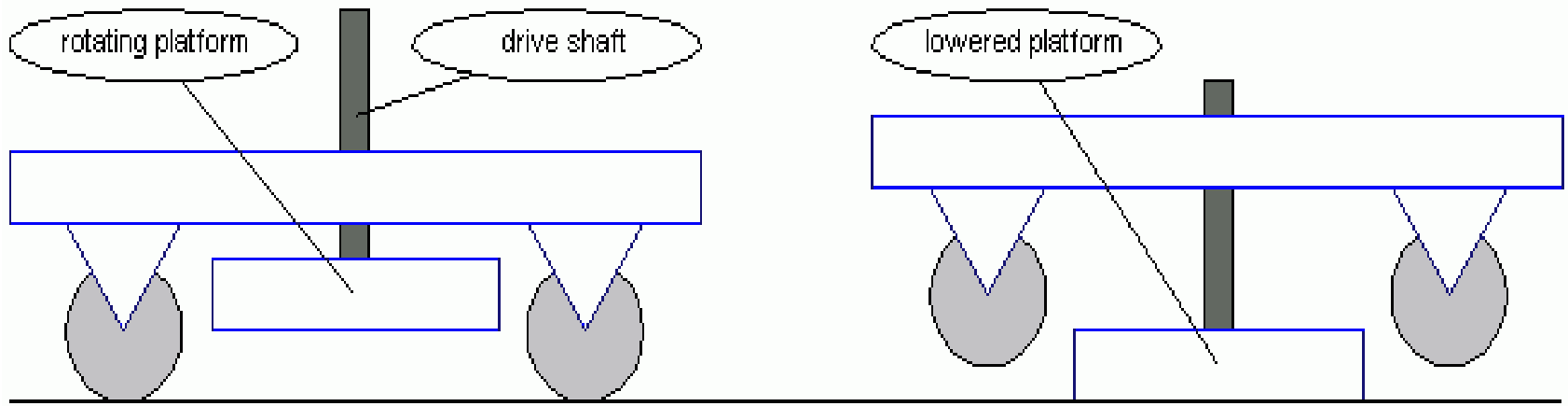


Disadvantages Of Car Type Drive

- The turning mechanism must be accurately controlled. A slight inaccuracy may cause large odometry errors
- The system is Non – Holonomic hence path planning is extremely difficult as well as inaccurate
- There are no direct directional actuators

Pivot Drive

- The most unique type of Locomotion system
- It is composed of a four wheeled chassis and a platform that can be raised or lowered



Pivot Drive Cont…

- The wheels are driven by a motor for translation motion in a straight line
- For rotation one motor is needed to lower/raise the platform & another to rotate the chassis around the platform
- This system can guarantee perfect straight line motion as well as accurate in – place turns to a desired heading

Complexity of Pivot Drive

- The system is quite complex in design
- A still more complex design uses only two motors. The wheels and the platform rotation are coupled to a single motor. When in translation the platform has no effect as it is above ground. And when turning, the wheels are off the ground due to the lowered platform
- The machine is restricted to only in – place turns. This may be an hindrance in some cases

Summary

- Different types of locomotion concepts
- Legged
  - Well suited for rough terrain
  - Problems with power consumption and stability
- Wheeled
  - Well suited for flat terrain
  - Different wheel configurations